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Electrical Engineering Research Laboratory
The University of Texas

Report No. 74

15 October 1954

Propagation of Millimeter Radio Waves in Low-Level Overwater Ducts

Prepared under Office of Naval Research Contract Nonr 375(01)
NR 071 032

ELECTRICAL ENGINEERING RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

REPORT NO. 74 15 October 1954

PROPAGATION OF MILLIMETER RADIO WAVES IN LOW-LEVEL OVERWATER DUCTS

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FIGURES

ABSTRACT

Radio signal strength measurements are reported for propagation tests in a low-level overwater duct. A wavelength of 4.3 millimeters was used on a 7-mile path, a wavelength of 8.6 millimeters on paths up to 24 miles and a wavelength of 3.2 centimeters on paths up to 44 miles. All transmitter and receiver heights used were less than 15 feet.

The signal level was found to be less than the free space value with decay rates per mile given approximately as follows:

Wavelength	Decay Rate in db per Mile Relative to Free Space	Theoretical Oxygen and Water Vapor Loss in db Per Mile
4.3 mm	3	2.0
8.6 mm	0.7	0.4
3.2 cm	0.3	0.0

The fluctuation range increased sharply as the wavelength decreased from 3.2 centimeters to 8.6 millimeters and increased still more as the wavelength decreased to 4.3 millimeters. The range of the fluctuation also increased approximately in proportion to distance.

I. INTRODUCTION

The Electrical Engineering Research Laboratory has conducted a series of experiments on the propagation of millimeter radio waves under Contract Nonr 375(01). Reports 60, 63 and 64 [1, 2, 3] described reflection studies made at a wavelength of 8.6 millimeters and an experimental comparison of these data with those obtained at longer wavelengths. The measurements were made on path lengths of less than one mile.

Report 69 [4] described the results of measurements at 8.6 millimeters on paths of 3.5, 7 and 12 miles in length and Report 70 [5] described the extension of the tests to a 50 mile line-of-sight path.

When generators for 4.3-millimeter wavelength became available to us, it was possible to make propagation measurements at this shorter wavelength. Since it was necessary to make the measurements using a crystal video type of receiver, the path lengths were limited to 3.5 and 7.0 miles and the data taken over these paths were given in Report No. 73 [6].

II. MEASUREMENTS DESCRIBED IN THIS REPORT

As an extension of the millimeter measurement program, tests were undertaken along the coast of Bolivar Peninsula near Galveston, Texas during July 1954. Paths of approximately 7, 12, 25 and 44 miles were used and these are shown in the map given in Figure 1. The curvature of the coast line permitted overwater paths with shore based terminals for all four paths.

Previous measurements [7] near Galveston had indicated that a low-level inversion of index of refraction usually existed over the water with the duct extending to a height of about 25 feet. The transmitting and receiving equipment were used at heights of 15 feet or less in order that they would be kept within the duct at all times. Transmitter heights of 6, 10 and 15 feet were used for each of the receiver heights of 4, 8 and 12 feet.

The 8.6-mm and 4.3-mm measurements were made over the paths for which their signals could be detected. For comparison purposes, 3.2-centimeter data were taken for all of the path lengths. The path lengths over which each of the three wavelengths were used are as follows:

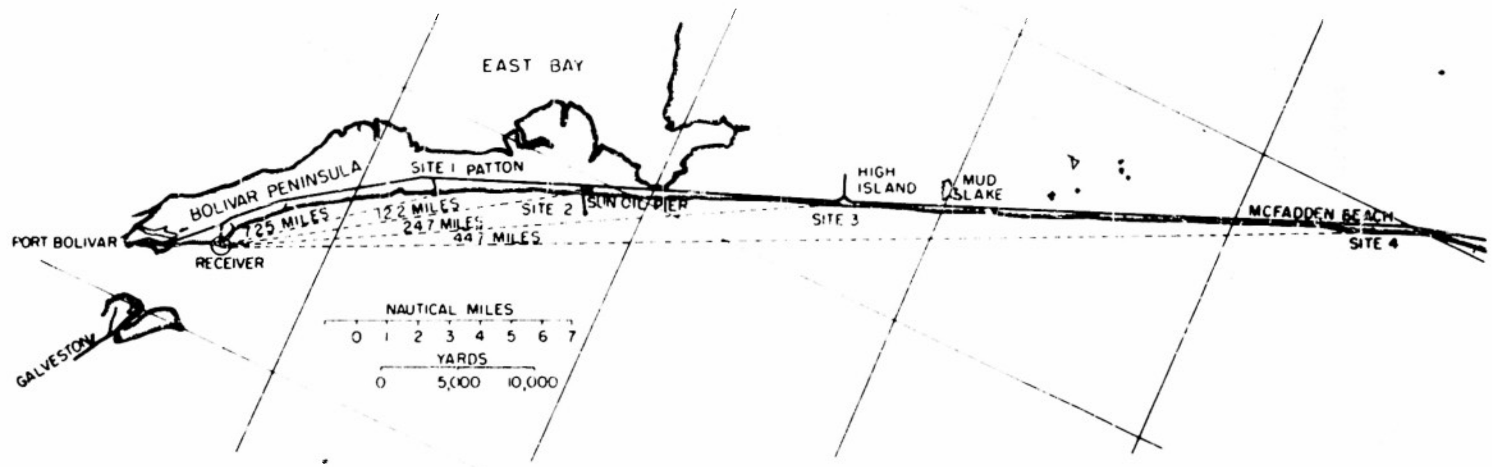
Wavelength	Path Length Used
4.3 mm	7.25 miles
8.6 mm	7.25, 12.2 and 24.7 miles
3.2 cm	7.25, 12.2, 24.7 and 44.7 miles

III. DESCRIPTION OF EQUIPMENT

The 4.3-millimeter tests were made with the same transmitting and receiving equipment as described in Report No. 73 [6]. The transmitter employed an experimental magnetron of the Columbia University design. The receiver was of the crystal video type using a Bell Telephone Laboratories experimental 5.4-millimeter crystal. The antennas used at the transmitter and receiver were horns with a gain of approximately 41 db and a beam width of approximately 2 degrees. The dynamic recording range of the receiver was 20 db.

The 8.6-millimeter equipment was previously described in Report No. 63 [2]. It employed a magnetron type 5789 as the signal generator at the transmitter and a superhetrodyne receiver with a QK291 klystron as the local oscillator. Horn antennas with gains of 27 db and 33 db were used in combinations to give the best recording level at the various path lengths. The dynamic recording range of the receiver was 40 db.

The 3.2-centimeter transmitter used a 2K39 klystron as the signal source and a parabolic reflector antenna with a gain of 33 db. The receiver was a superhetrodyne type with a 30 db parabolic reflector antenna. A calibrated attenuator between the receiving antenna and the crystal mixer was used to adjust the recording level at each of the path lengths. The dynamic recording range of the receiver was 36 db.



RADIO TEST PATHS ALONG BOLIVAR PENINSULA

FIG. 1

GMC van type trucks were used for the transmitting and receiving stations. A 15 foot elevator was mounted on the rear of each truck. The transmitters and receivers for the various frequencies were alternately mounted on the platforms of the elevators and moved successively to the heights at which data were taken. A view of the 8.6-millimeter transmitter mounted on the elevator is shown in Figure 2 and the 8.6-mm receiver is shown in operating position in Figure 3.

IV. CALIBRATION

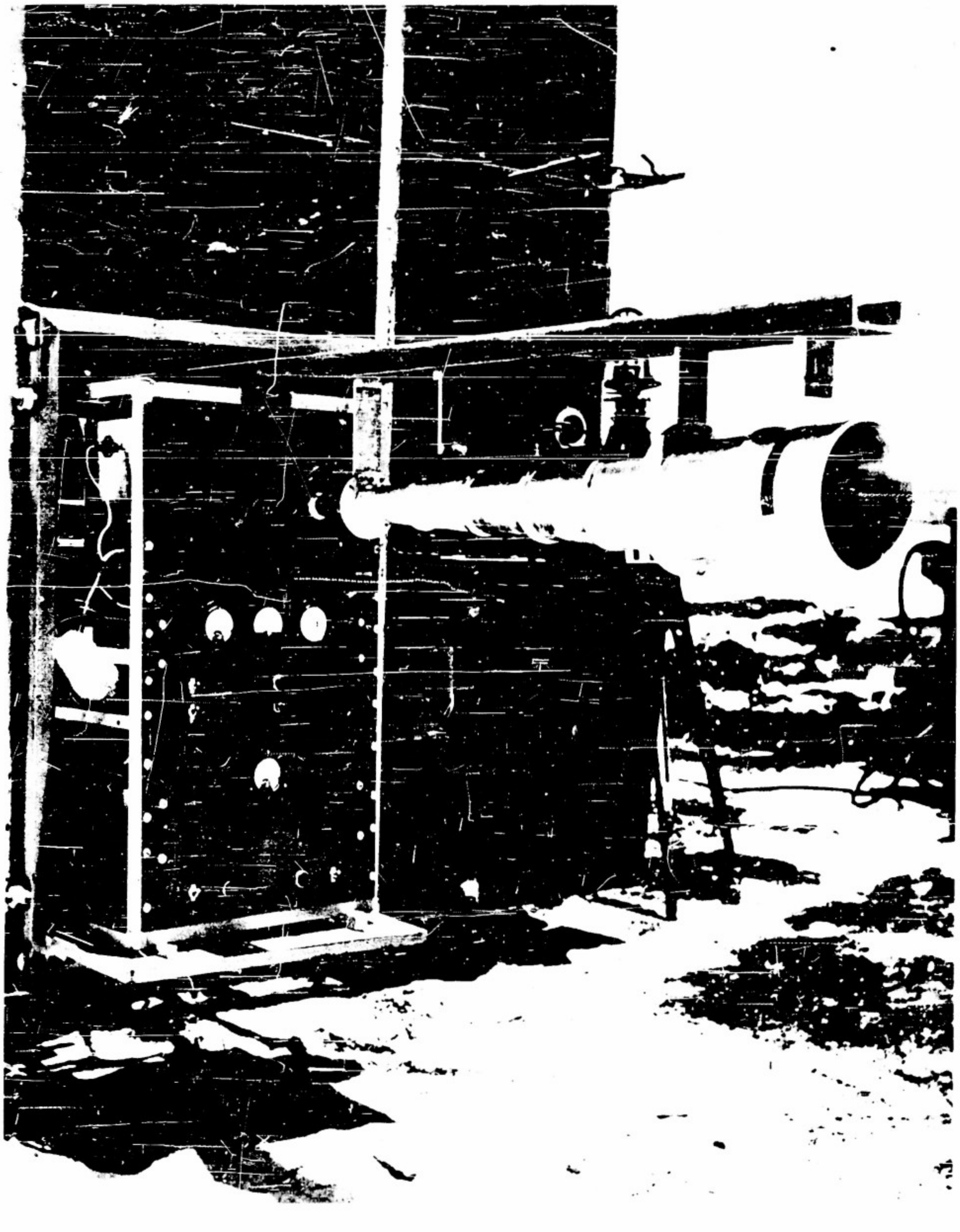
The reference signal level was that signal level which was received over a 2600 foot path for a given relative power setting of the transmitters with the antennas used during the measurements along the Gulf of Mexico Coast. Recordings of signal strength versus height were made for the 2600 foot path in order that the reflected component of the signal could be computed and the reference level be that of the direct component alone. The signal strengths measured along the Gulf are expressed in decibels relative to the signal level expected for an inverse square law power variation of the signal for the various path lengths relative to the 2600 foot reference path.

V. RADIO DATA

The operating procedure was to take a set of 5 minute samples for each of the frequencies for which a signal could be obtained. The set consisted of time runs with the transmitter at 6, 10 and 15 feet for each of the receiver heights of 4, 8 and 12 feet.

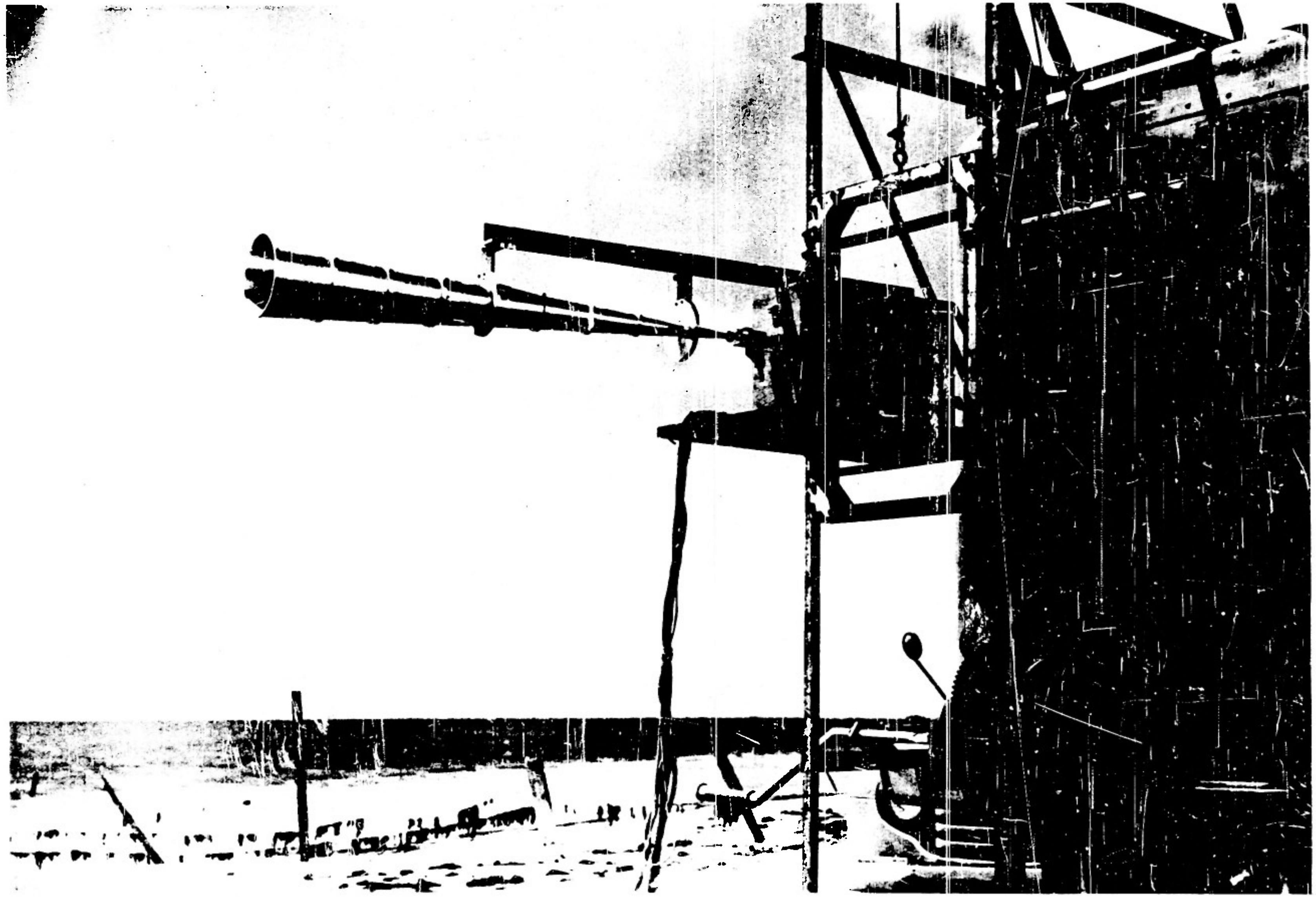
The complete results of these measurements are shown in Figures A1 through A8 of the appendix. The circles in these figures indicate the median values of the five minute runs and the lines through them show the range of the fluctuations. Where the median level is less than the noise level, no circle is shown. The fluctuation range sometimes extended into the noise level, in which case the fluctuation range line terminated on the noise level line. For a few of the samples, the signals did not exceed the noise level and these cases are indicated by "No Data." The day of the month and the time of day are shown for each sample. No 4.3-millimeter signal was noted on paths of 12 miles long or longer. No 8.6-millimeter signal was noted on the 44 mile path.

The general level and the fluctuation range of the signal are illustrated by the minimum, median and maximum signal exceeded on fifty percent of the test samples. These values are given in Table 1. The median values are shown in Figure 4 and the ranges between the minima and maxima are shown in Figure 5.



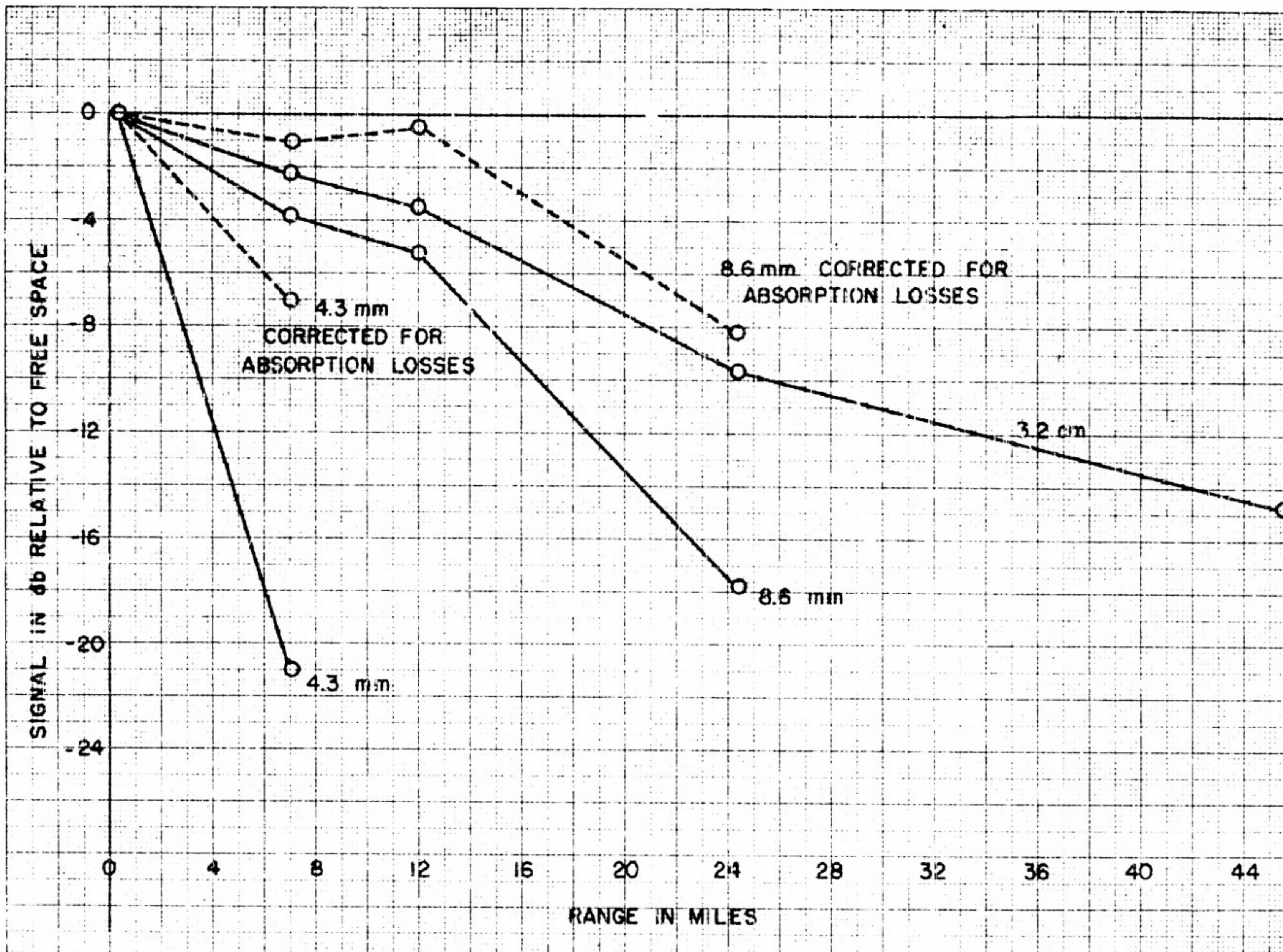
VIEW OF 8 6 MILLIMETER TRANSMITTER ON ELEVATOR PLATFORM

FIG. 2

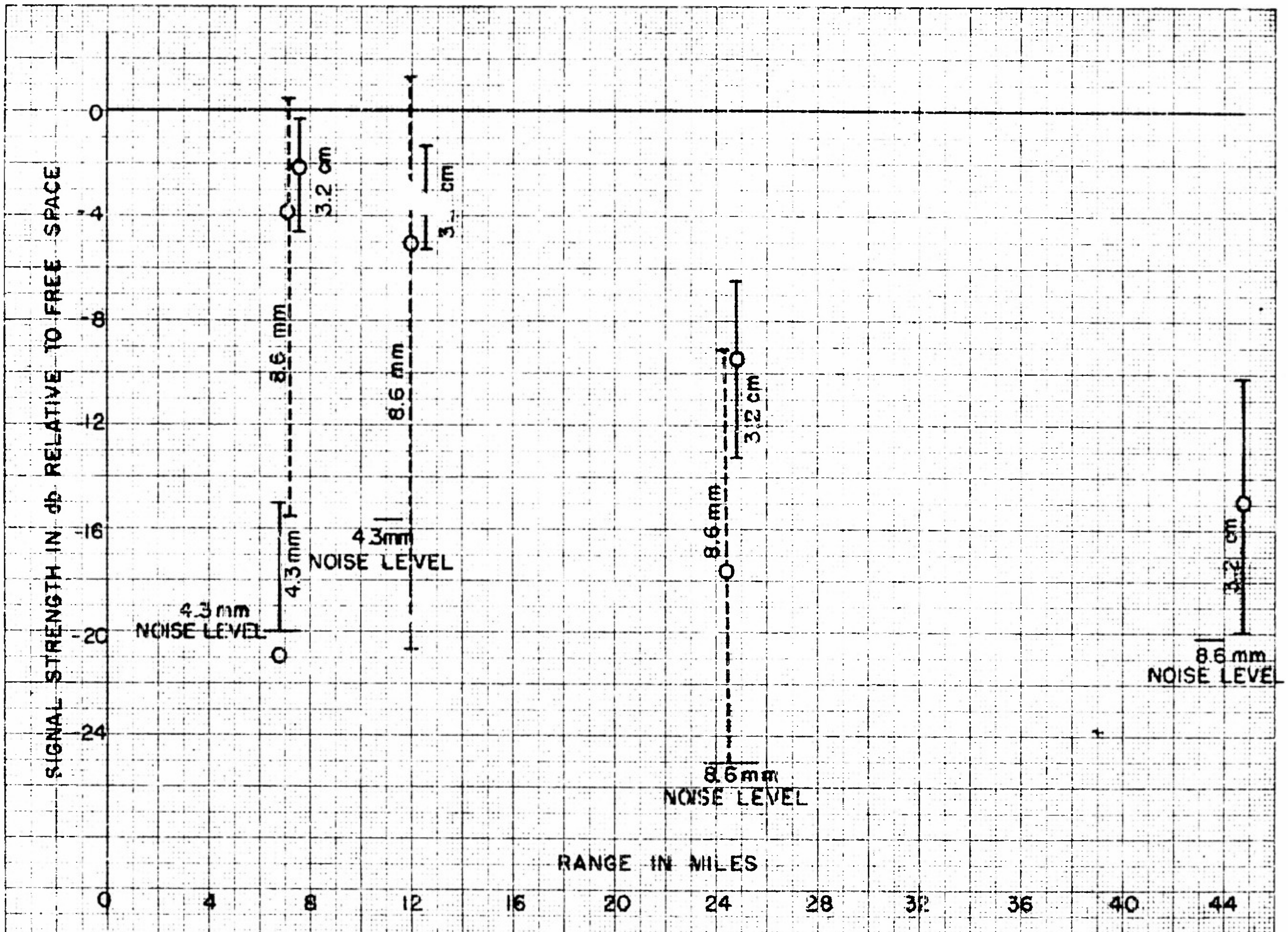


VIEW OF 8.6 MILLIMETER RECEIVER ON ELEVATOR PLATFORM

FIG. 3



SIGNAL EXCEEDED BY MEDIANS OF 50% OF THE SAMPLES
FIG 4



RANGES BETWEEN MINIMUM SIGNAL AND MAXIMUM SIGNAL EXCEEDED ON 50% OF SAMPLES

FIG. 5

TABLE I

SIGNALS EXCEEDED IN 50% OF THE SAMPLES
IN DB RELATIVE TO FREE SPACE SIGNALS

Distance in Miles	7.25	12.2	24.7	44.7
4.3 Millimeters				
Maxima	-15.3	Less than -15.6		
Median	-21 (est.)			
Minima	-			
8.6 Millimeters				
Maxima	+ 0.5	+ 1.1	- 9.2	Less than -20
Median	- 3.8	- 5.1	-17.8	
Minima	-15.3	-20.8	Less than -25	
3.2 Centimeters				
Maxima	- 0.3	- 1.3	- 6.8	-10.2
Median	- 2.1	- 3.4	- 9.7	-14.9
Minima	- 4.8	- 5.4	-13.2	-19.8

It was necessary to estimate the median signal for the 4.3-millimeter signal on the 7.25 mile path since the median was less than the noise level in slightly more than half of the runs. The estimate was made by finding the median difference between the maximum and median values and by subtracting this difference from the maximum signal exceeded in 50% of the samples.

In Figure 4, the median signals for the 4.3-mm and 8.6-mm wavelengths were increased by the absorption losses to obtain a new set of points through which the dotted lines were drawn. For this absorption correction, the values obtained by previous measurements of this Laboratory [5, 6] were used. A value of water vapor content of 21 grams per cubic meter was used since this was the average water vapor content observed from which there was little deviation. The water vapor and oxygen corrections used are as follows:

	Absorption Loss in db/mile	
	Water Vapor	Oxygen
3.2 centimeters	0	0
8.6 millimeters	0.36	0.32
4.3 millimeters	0.84	0.80

VI. DESCRIPTION OF METEOROLOGICAL STATION

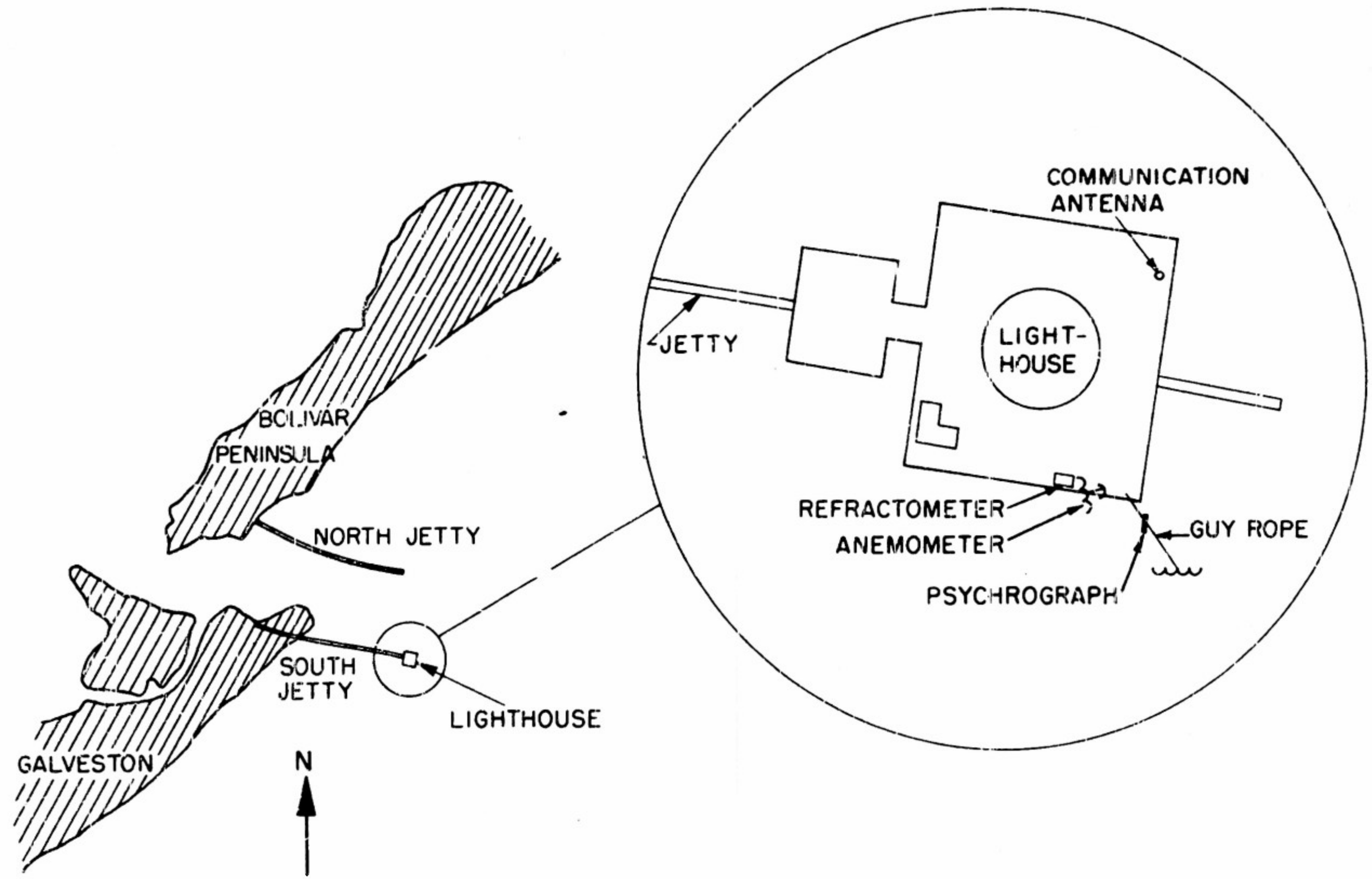
In order to obtain meteorological measurements representative of overwater conditions, a sounding site was established on the Galveston Lighthouse at the end of the South Jetty. Permission to make the measurements and to locate two of our staff personnel on the Lighthouse for the period from 13 July through 21 July was obtained from the 8th Coast Guard District at New Orleans. The assistance given us by both the Lighthouse and Base Station personnel at Galveston is gratefully acknowledged.

The meteorological station was located on the southeast corner of the main platform approximately 45 feet above mean water level. Unobstructed measurements were obtained from this location for wind directions from ESE through WSW. In order to obtain data representative of air having long overwater trajectories with a resulting reasonable horizontal homogeneity only data with wind directions between ESE and SW were considered. Winds to the west of southwest would bring air out to the measurement site and over the radio path which would exhibit large scale horizontal variations due to the rapid modification of an overland airmass as it moves out over water. A schematic view of the meteorological site and its orientation with respect to the shore is shown in Figure 6. A photographic view of the Lighthouse is given in Figure 7.

Meteorological equipment consisted of a wet and dry bulb thermistor-type psychrograph (artifically ventilated), an anemometer, a microwave refractometer and a bead thermistor. The psychrograph was used to obtain periodic air temperature and moisture gradients in the 45 foot interval above the water surface while the other instruments were mounted at the platform level and used to record selected time variations of total wind speed, refractive index and air temperature. A pulley arrangement was used with the psychrograph to obtain the necessary height variations. A day's operation would consist generally of four series of four vertical ascents, beginning approximately at 0900, 1000, 1300 and 1500 CST with each ascent requiring about 10 minutes to complete. A minimum duration of one minute was allowed for the instrument to come into equilibrium at each of the eight levels used between the surface and 45 feet. The psychrograph had a lag coefficient of about 5 seconds and measured dry bulb and wet bulb temperature changes to within 0.1°C. Absolute measurements were probably accurate to within 0.3°C. The vertical refractive index profiles were computed from the wet and dry bulb temperatures.

The total wind speed measurements were made by a standard three-cup anemometer whose output was recorded on an Esterline Angus meter on a nearly continuous basis. A chart speed of 3 inches per hour was used except for occasional recordings were made throughout each day at 3 inches per minute. Simultaneous temperature and refractive index recordings were made at certain intervals throughout the observation period to study their corresponding time variations and to obtain a measure of atmospheric moisture content variations. The equipment for these measurements involved the Crain microwave refractometer [8] and a sensitive bead thermistor [8]. Esterline Angus recording meters with a frequency response of about 2 cycles per second were used with both index and temperature variations.

Reference should be made to Electrical Engineering Research Laboratory Report No. 36 which describes a similar meteorological research program for the Galveston area where the facilities of the Lighthouse were also used. Other meteorological measurements made in this area are described elsewhere [7, 9].



METEOROLOGICAL STATION ON GALVESTON LIGHTHOUSE
SHOWING EQUIPMENT ORIENTATION WITH RESPECT TO SHORELINE

FIG. 6

VIEW OF GALVESTON LIGHTHOUSE

FIG. 7

VII. REPORT OF METEOROLOGICAL DATA

The general meteorological pattern over the period between 13 and 21 July consisted of an essentially unvarying circulation around the western end of the Azores semi-permanent high pressure area giving on-shore SSE-SSW surface winds. Wind speeds during the 14th and 19th varied from between 4 and 7 mph during morning hours (0900-1100) and increased up to between 8 and 11 mph during the afternoon. Noticeable land breezes were detected on two occasions with shifts from WNW to SSW at 1000 on 14 July and at 1130 on 15 July. The surface winds during the second half of the observation program showed a uniform direction between S and SSW with speeds varying from 9 to 14 mph during the day. Wind speeds up to 19 mph were measured by late afternoon of the 21st. White caps on the water surface were common during the second observation week and average wave heights increased from approximately 1 to 2 feet over the period between 13 and 16 July to approximately 2 to 3 feet from 19 to 20 July and to 3 to 4 feet by the afternoon of the 21st. Wave directions were almost exclusively from the south. The general weather situation featured a rather uniform high scattered to broken amount of cirrostratus cloud and a lower scattered amount of cumulus. Cumulus growth and activity sufficient to form general showers occurred during the morning hours of the 14th.

With the exception of observations taken during the periods when the above few weather anomalies were occurring, the following summary statements may be made concerning the average values of the temperature measured between 0900 and 1700 CST.

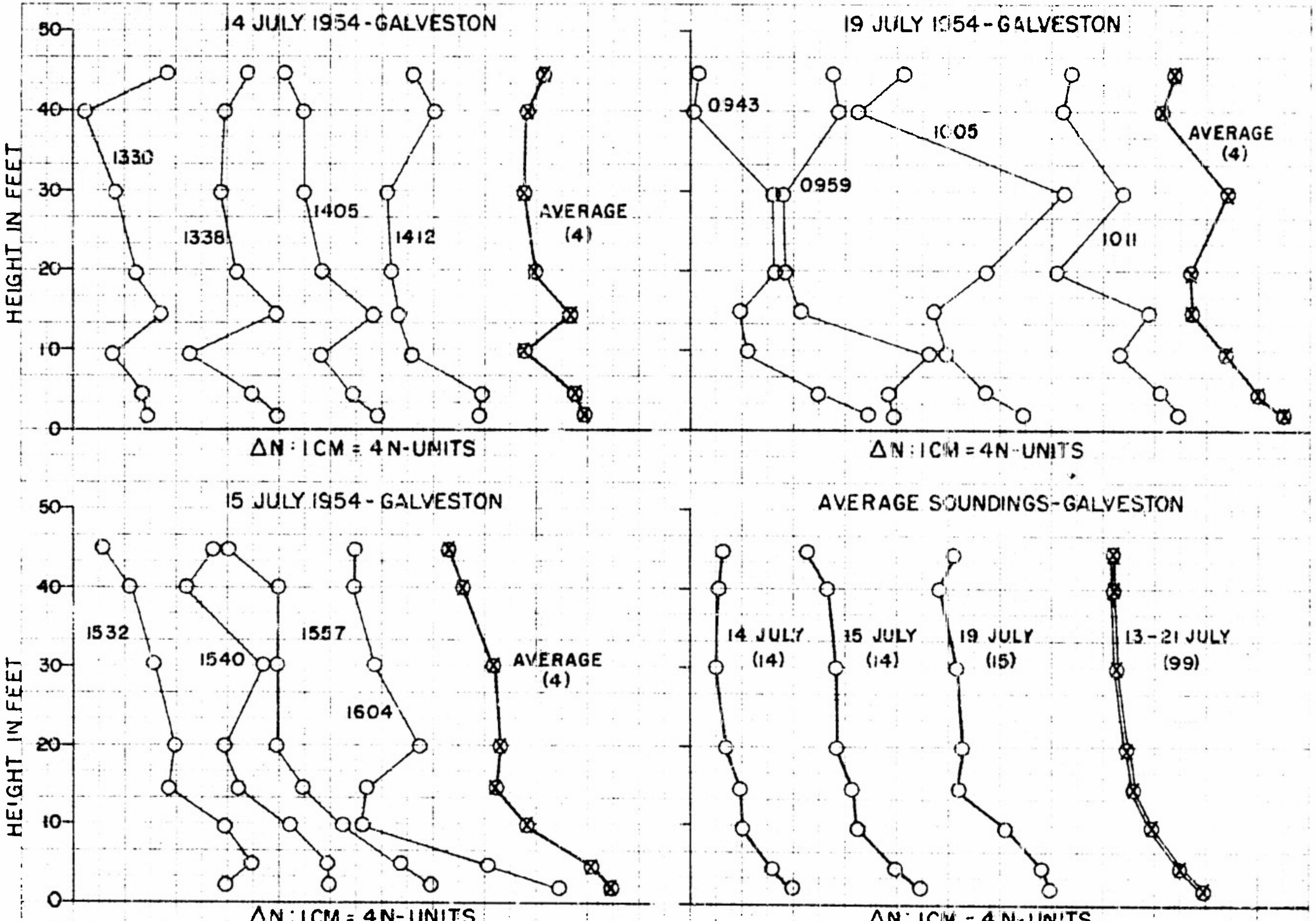
a. Water surface temperatures did not vary more than 0.8°C from an average value of 30.2°C.

b. Air temperatures at the 45-foot level did not vary more than 0.3°C from an average value of 29.1°C.

c. The temperature lapse rate between a level of about 2.5 feet and 45 feet above the water surface was approximately twice the dry adiabatic lapse rate. The actual temperature differences varied from 0.0 to 0.8°C with 0.3 to 0.5°C representing a normal range of values.

d. Time variations of temperature measured with the bead thermistor at the 45 foot level showed maximum deviations from an average value of no more than 0.1°C.

In direct contrast to the above, however, moisture measurements showed no such homogeneity. Based on the relatively slow response of the psychrograph, moisture differences of as great as 3 mbs were found between successive observation levels. Soundings made within 15 minutes of each other might bear no resemblance to each other. Some of this variability is illustrated in Figure 8 which gives some selected individual and average index gradients computed from the dry and wet bulb temperature soundings taken during the period between 13 and 21 July. All of the soundings showed the general decrease in index to be expected for low level overwater measurements in an unstable atmosphere where the water is warmer than the air. The decrease in index is entirely attributable to the decrease in water vapor content since temperature was constant. It is not until we average the entire 99 individual soundings, however, that a smooth index-height variation is obtained. Even daily averages do not eliminate anomalies in the index profile. There is certainly little doubt that these striking height and time variations in atmospheric moisture content arising essentially from vertical motions of moist air near the surface to



SELECTED INDIVIDUAL AND AVERAGE LOW LEVEL OVERWATER REFRACTIVE INDEX SOUNDINGS

FIG. 8

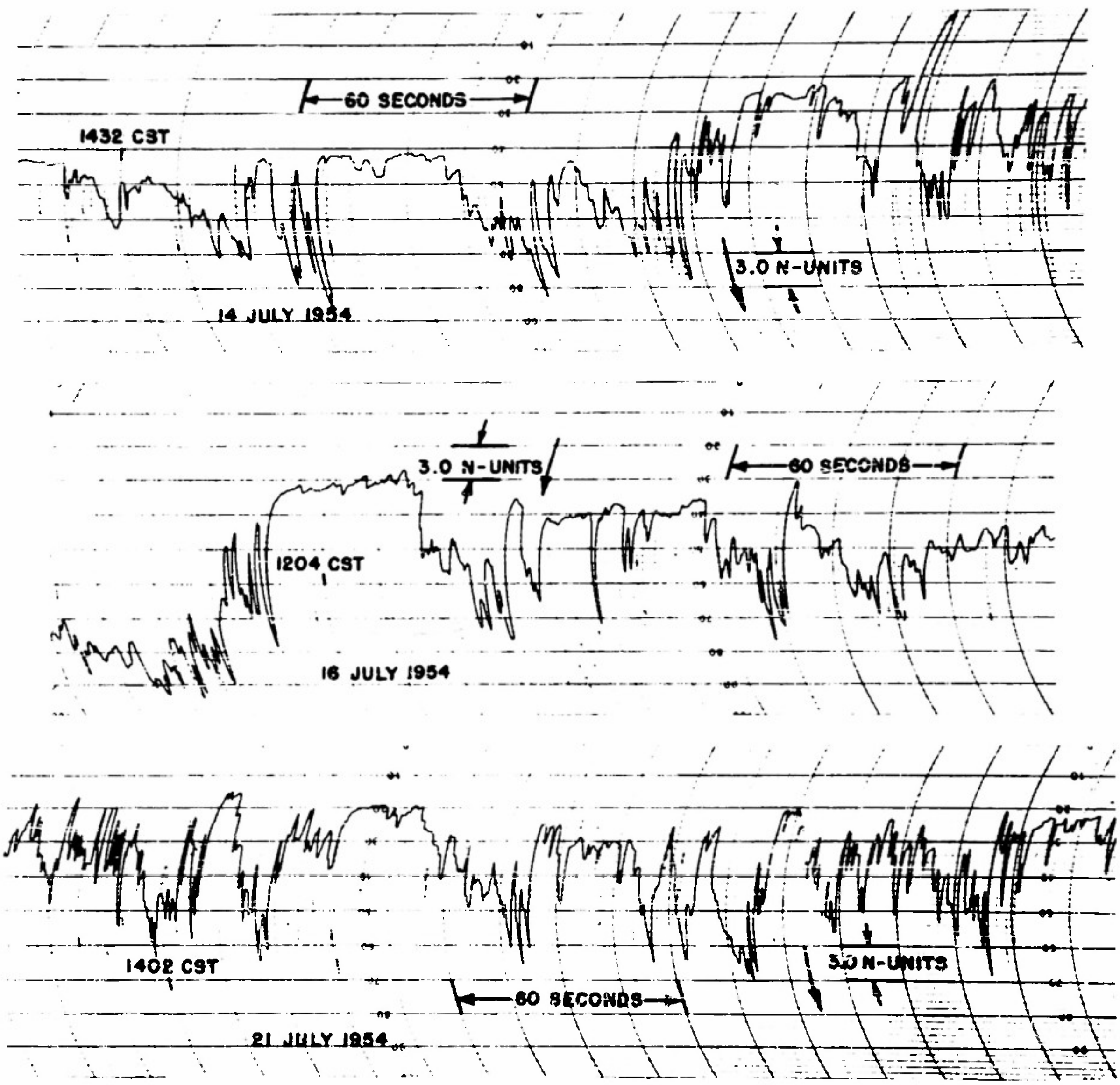
higher elevations, also give rise to major horizontal variations in refractive index. Incidentally, it might be noticed that the average index profile obtained during this project showed a duct whose height was between 30 and 45 feet although greater than 80 per cent of the total index decrease of 7 N-units from the 2 foot reference level had occurred by the time the 20 foot level had been reached. If a 5-foot reference is used the total N deficit to the duct height is 5 N-units. These values can be compared with duct heights and N differences of about 33 feet and 3.5 N-units for July 1949 measurements [10] and about 25 feet and 4 N-units for the August 1947 measurements [7] both using reference level at approximately 5 feet. Fifteen foot tower heights certainly fell within the low level duct.

In order to obtain somewhat more detailed information on the time variations in moisture content at a given level, simultaneous temperature and index-of-refraction recordings were made at selected intervals. Although the existence of these variations is well known, previous measurements of the frequency components of these variations have heretofore been limited to sensing elements with relatively large lag coefficients and continuous observations for true overwater conditions are practically unknown*. Since the theory of operation of the refractometer and the method of deducing moisture fluctuations from combined temperature and index recordings has been given previously [8], it will be sufficient to state here, for the case where temperature variations may be assumed as zero, that moisture changes in millibars may be obtained by dividing the corresponding index changes by a factor whose value depends on the mean temperature and moisture but which is approximately 4.2.

Several points can now be made from a study of the sections of original refractive index recordings reproduced in Figure 9. First of all there appears to be two more or less significantly different periods involved although intermediate values certainly exist. The low frequency variation may have periods of a minute or more and may give a relatively quiet index pattern for records covering 30 to 45 seconds when minima exist in the refractive index recording. Average maximum values are difficult to determine due to the confused fluctuation pattern at that time but changes from these average maxima to minima appear to be between 8 and 12 N-units. These changes are equivalent to moisture changes of about 2 to 3 millibars. The second type of variation is of a much higher frequency with certain periods, as shown particularly for the 21 July sample, as low as 0.5 seconds. The magnitudes of some of these rapid variations exceed those of the slower type and trough to peak variations almost as high as 15 N-units, equivalent to 3.5 millibars, are observed. Notice in the data for 14 July that a total index change of 85 N-units occurs in a little less than 3 minutes! In general the portions of the recordings showing the highest RMS fluctuations are those whose average index values lie between high near surface refractive index conditions and the lower refractive index conditions at higher altitudes.

Although a comprehensive explanation of these phenomena would involve a much more detailed set of refractive index and wind speed measurements at various heights and a knowledge of the water surface variations, certain general features of an overwater moisture distribution may be postulated. These are:

* Some refractive index recordings over the surface of a small inland lake are reported by Staley [11].



SECTIONS OF ORIGINAL RECORDINGS OF REFRACTIVE INDEX FLUCTUATIONS

FIG. 9

a. An average moisture change between some reference level near the surface and the level at which the rate of change of moisture is approximately zero is some small percentage of the total moisture change using the surface as a reference level. (In the measurements reported here, $e_{25} - e_{45} = 1.5$ mbs while $e_{sfc} - e_{45} = 14$ mbs). As a result vertical motion from near the surface brings air of significantly greater moisture content to a given level over average environment values. The reverse is true for descending air.

b. There thus tends to be a "floor" under the index or moisture values below which variations do not normally occur. This floor represents the moisture content of the air at the level where the rate of change of moisture with height is approximately zero.

c. The short period index fluctuations occuring while at or near this "floor" level are due to the passage of relatively small, higher moisture content air masses past the measuring level, possibly as a result of vertical motion initiated by especially steep waves. Note that the horizontal dimensions of the eddy giving rise to the single index peak between 1205 and 1206 on the 16th would be about 10 feet for the existing 10 mph mean wind speed.

d. The long period index fluctuations will cover much larger horizontal areas ranging from 100 to 1000 feet. This condition may arise more as a result of an increase in the thermal instability of the layer near the surface or as a result of an increased vertical wind shear giving greater mechanical mixing. The two effects cannot as yet be separated. The effect of long period swells in the water surface is probably unimportant.

A final question involves the extent to which a horizontal integration of an instantaneous refractive index distribution can be approximated by a time integration at a given point. Although a radio duct existed at all times somewhere within the first 50 feet above the water, there were significant departures from the classical, constant, horizontally-stratified model of such a duct. Certainly the resulting large signal strength variations occurring at fixed levels would indicate that there was little tendency for the variations from an average index-height distribution over the radio path to effectively cancel each other, an effect which might be expected if the index variations all resulted from small rapidly moving blobs. Here, of course, we are concerned with propagation paths in which the horizontal dimensions of the atmospheric blobs are some significant percentage of the path dimension itself.

VIII. MODE THEORY OF TRAPPING

In a previous report [12], the propagation of 3.2 centimeter radio waves was analyzed for a low-level duct typical of the situation to be found along the paths used for these present tests. The meteorological soundings made concurrently with these tests indicated that the previous model was a satisfactory approximation. This model was of the linear-exponential type where the modified index of refraction M is given in terms of height h by the equation

$$M - M_o = -10.5 + 0.04h + 10.5e^{-0.14h}$$

where M_0 is the index of refraction at the surface of the water.

As pointed out previously, the index profile fluctuates considerably with time and presumably with distance. Thus while an average refractive index distribution may be used for approximate computations, neither it nor any single height distribution provides an accurate model for determining the actual radio time and height variations.

By use of the work of Pekeris and Ament [13], it is found that for a wavelength of 3.2 centimeters the first mode is very strongly trapped by the index model chosen while the second mode has considerable attenuation. The 8.6-millimeter waves will, however, have three modes strongly trapped and the 4.3-millimeter waves will have six modes trapped. This means that the height-gain function may be very complex and interference between the modes may be expected.

For an example of this interference, the 8.6-millimeter data at the 12.2 mile range may be noted. With the transmitter at six feet, the median signal for a receiver height of 8 feet was less than receiver heights of either four or twelve feet.

On the first occasion when an off-shore wind was noted, 3.2 centimeter measurements were being made at a range of 12.2 mile (Run No. 6). The signal at this time decreased very rapidly with decreasing transmitter and receiver heights and at the lower levels was 10 to 15 db below the corresponding signals taken at other times.

On the second occasion when an off-shore wind was noted (Run No. 10), the 8.6-millimeter measurements were being made at a range of 24.7 miles, and the signal was strong at all levels.

There was some indication that all of the 3.2-centimeter signals measured in the morning were weaker than the corresponding measurements in the afternoon. This characteristic was not noted however, for the 8.6- and 4.3-millimeter signals.

For a perfectly trapped mode without loss, the signal level would vary inversely as the square root of distance. This would suggest that the decay rate would be less than the free space decay rate. The measurement indicated however that the signal decreased with distance faster than the free space value. This is attributed to the fact that the index of refraction is not horizontally stratified and to the roughness of the water.

The 8.6-mm and the 4.3-mm waves have significant absorption due to resonant water vapor and oxygen molecules. As shown previously an attempt to remove these losses was made for the data shown in Figure 4. The resultant curves, shown dotted in the figure, indicate that except for these losses, the 8.6-millimeter waves would have a slower decay rate than that for the 3.2 centimeter waves and that conversely the 4.3-millimeter waves would have a somewhat higher decay rate.

For the seven mile path, the upper heights were within the light of sight and the mode theory approach would not be a satisfactory one for this range.

IX. POWER SPECTRA OF SIGNAL FLUCTUATIONS

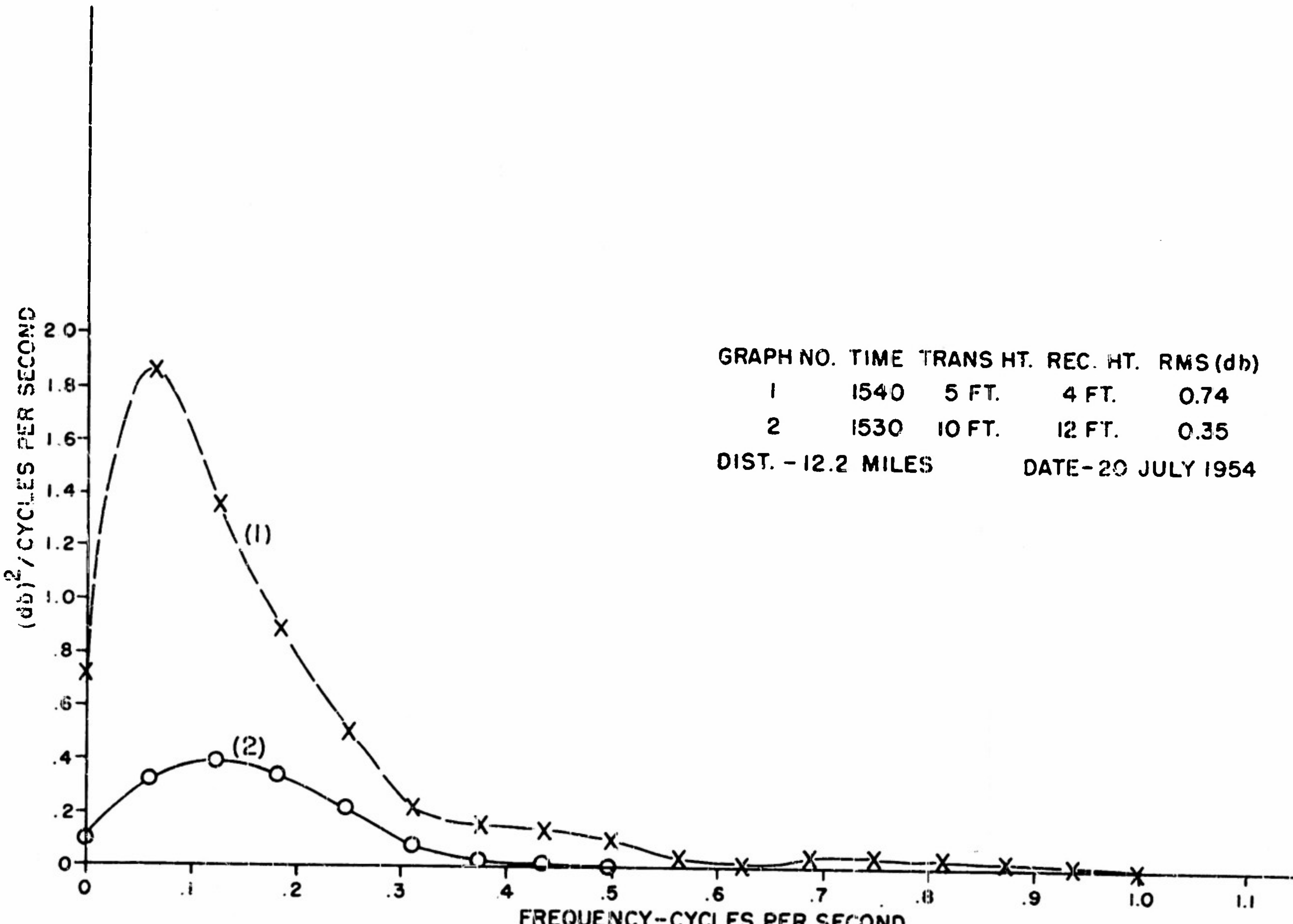
In order to obtain a quantitative measure of the frequency distribution of the signal strength fluctuations, power spectra were determined for several selected periods by the method described in a previous report [14].

Power spectra for two 3.2-cm wavelength signal recordings are shown in Figure 10. These samples were for the path length of 12.2 miles and show the sharp contrast in the amount of fluctuations that may be associated with changes in transmitter and receiver heights. In this case, graph (1) was for higher terminal heights and showed a greater amount of fluctuation than was noted in graph (2) for lower terminal heights.

A similar comparison of spectra for 8.6-mm wavelength signal recording is shown in Figure 11. These samples were also taken over the path length of 12.2 miles. The contrast in the fluctuation range was more striking for these examples, since they were taken with the same receiver height and a difference of only five feet in the transmitter heights. Graph 1, for a transmitter height of 15 feet showed much stronger fluctuations than did graph 2 for a transmitter height of 10 feet.

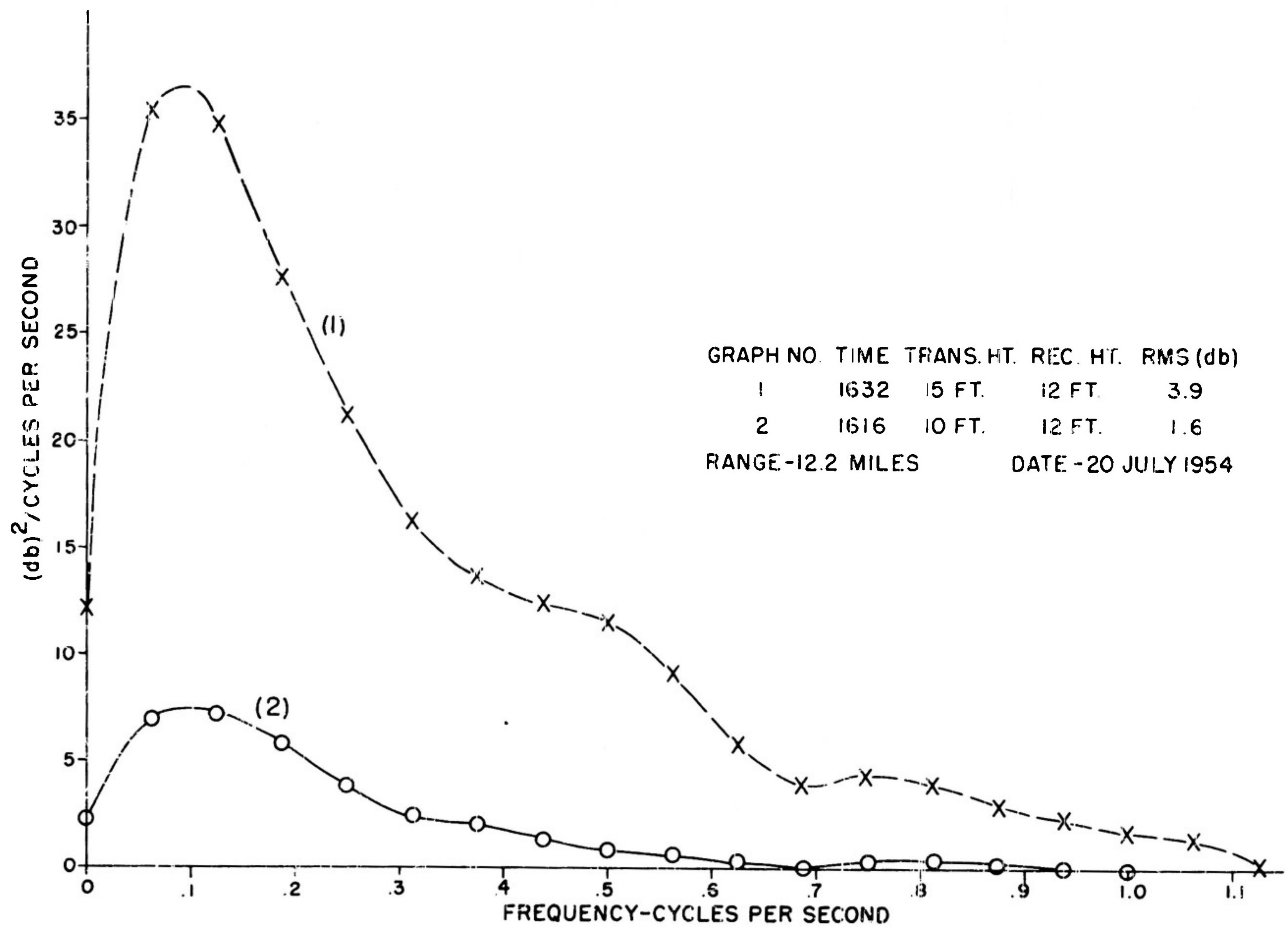
A comparison is made in Figure 12 of the spectra of the signal fluctuations for the three wavelengths of 3.2 cm, 8.6 mm and 4.3 mm. These data were taken over a path length of 7.25 miles with the same transmitter and receiver heights. The sharp increase in the magnitude of fluctuations for the millimeter wavelengths as compared to the 3.2-centimeter wavelength data is characteristic of all of the measurements. In these samples, the RMS of the 4.3-mm sample was slightly lower than that of the 8.6-mm sample. In general, however, the 4.3-mm data appeared to have the greater amplitude of fluctuation. The amount of data for comparison was very limited since most of the 4.3-mm data faded into the noise and thus prevented an observation of its complete fading range.

It is noted from Figure 12 that fluctuations for the shorter wavelengths contained components at considerably higher frequencies than for the 3.2-cm wavelength.



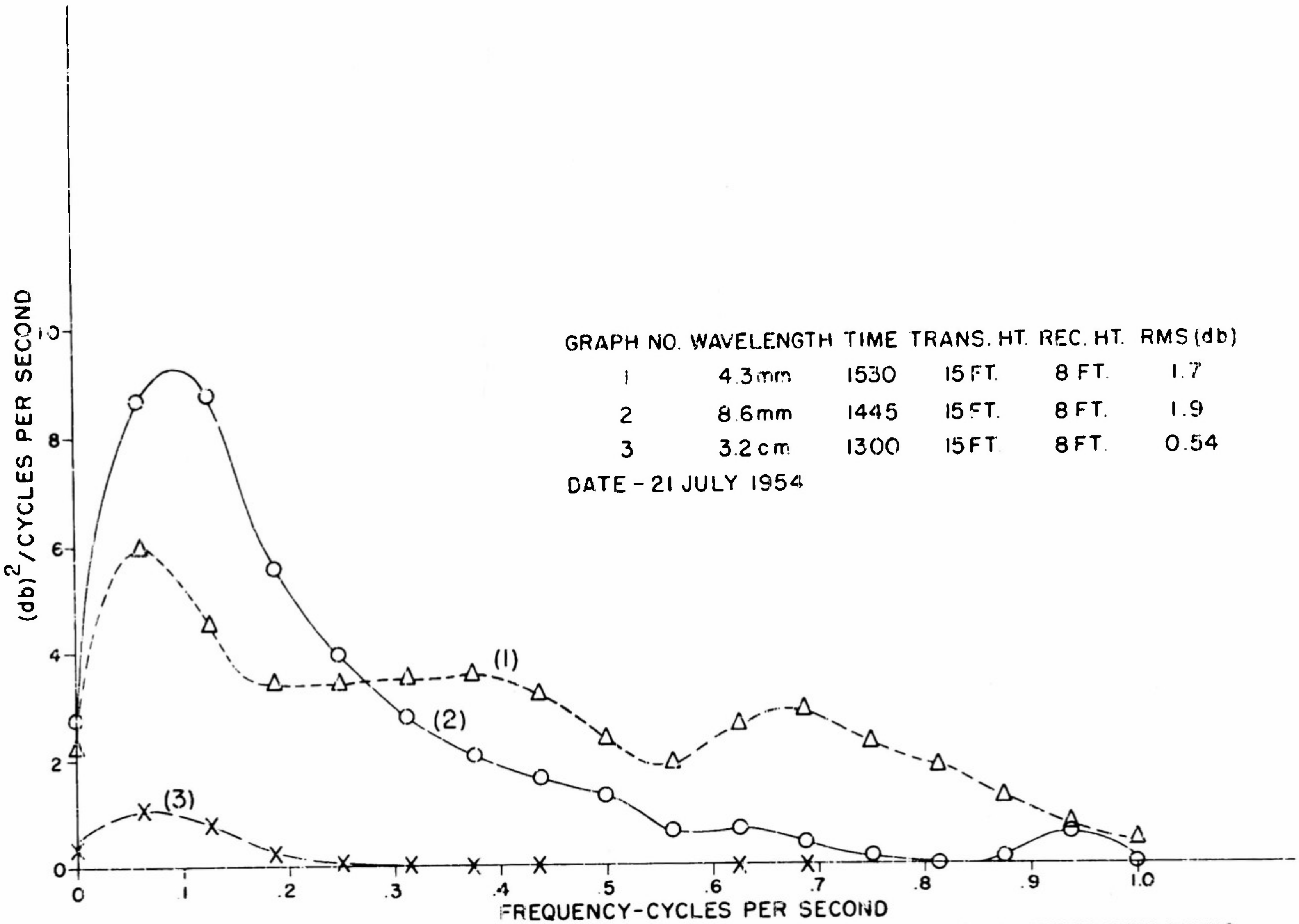
COMPARISON OF POWER SPECTRA OF TWO 3.2 cm. SIGNAL STRENGTH RUNS

FIG. 10



COMPARISON OF POWER SPECTRA OF TWO 8.6mm. SIGNAL STRENGTH RUNS

FIG. 11



COMPARISON OF POWER SPECTRA OF 3.2-cm, 8.6-mm, AND 4.3-mm SIGNAL STRENGTH RUNS

FIG. 12

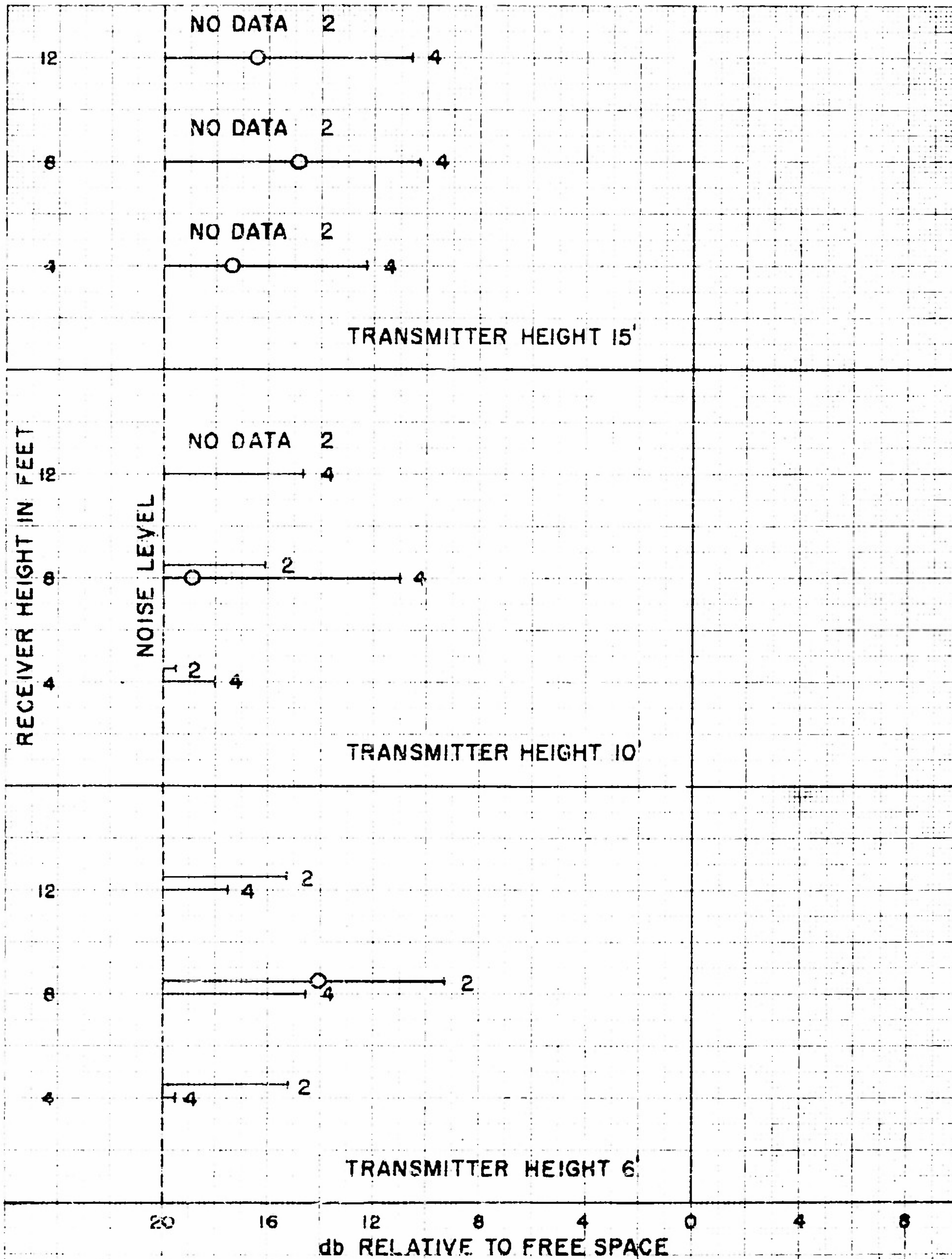
APPENDIX

TABLE SHOWING DETAILED MEASUREMENT SCHEDULE.

FIGURES SHOWING MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR ALL DATA OBSERVATION PERIODS.

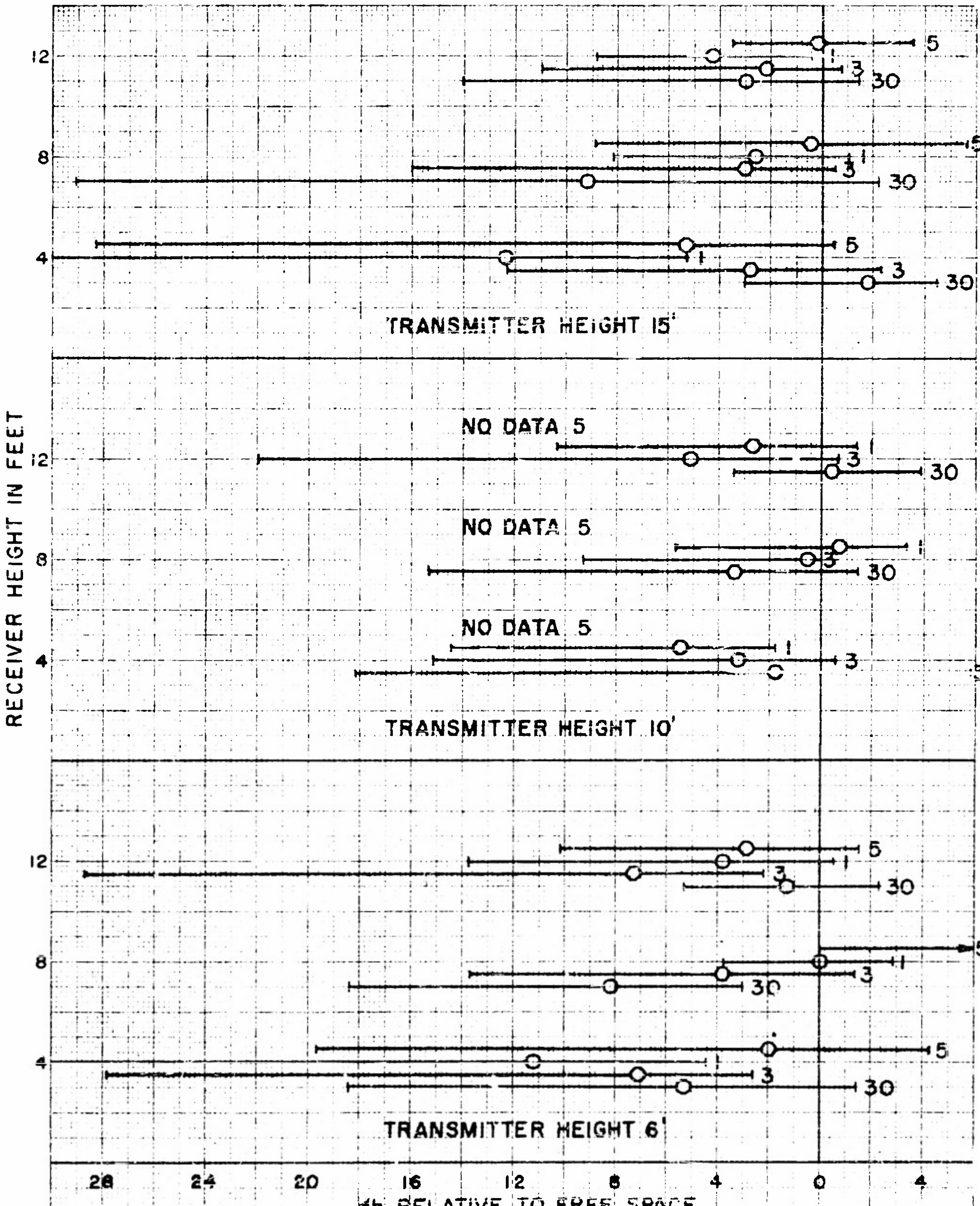
SAMPLING SCHEDULE

DATE	RANGE IN MILES	TIME	WAVELENGTH	RUN NO.
July 13, 1954	7.25	0915-0945	8.6 mm	1
		1100-1200	4.3 mm	2
		1200-1250	8.6 mm	3
		1300-1400	4.3 mm	4
		1600-1640	8.6 mm	5
July 14, 1954	12.2	1000-1100	3.2 cm	6
		1110-1200	8.6 mm	7
		1350-1430	3.2 cm	8
		1440-1600	8.6 mm	9
July 15, 1954	24.7	1115-1150	8.6 mm	10
		1155-1230	3.2 cm	11
		1400-1445	3.2 cm	12
		1500-1545	8.6 mm	13
July 16, 1954	44.7	1030-1120	3.2 cm	14
		1400-1440	3.2 cm	15
July 19, 1954	24.7	0945-1025	3.2 cm	16
		1040-1115	8.6 mm	17
		1130-1230	3.2 cm	18
		1235-1320	8.6 mm	19
		1320-1405	3.2 cm	20
		1500-1540	8.6 mm	21
July 20, 1954	12.2	0955-1015	3.2 cm	22
		1025-1250	8.6 mm	23
		1300-1350	3.2 cm	24
		1415-1500	8.6 mm	25
		1500-1550	3.2 cm	26
		1605-1635	8.6 mm	27
July 21, 1954	7.25	1000-1034	3.2 cm	28
		1305-1350	3.2 cm	29
		1400-1440	8.6 mm	30
		1455-1530	3.2 cm	31



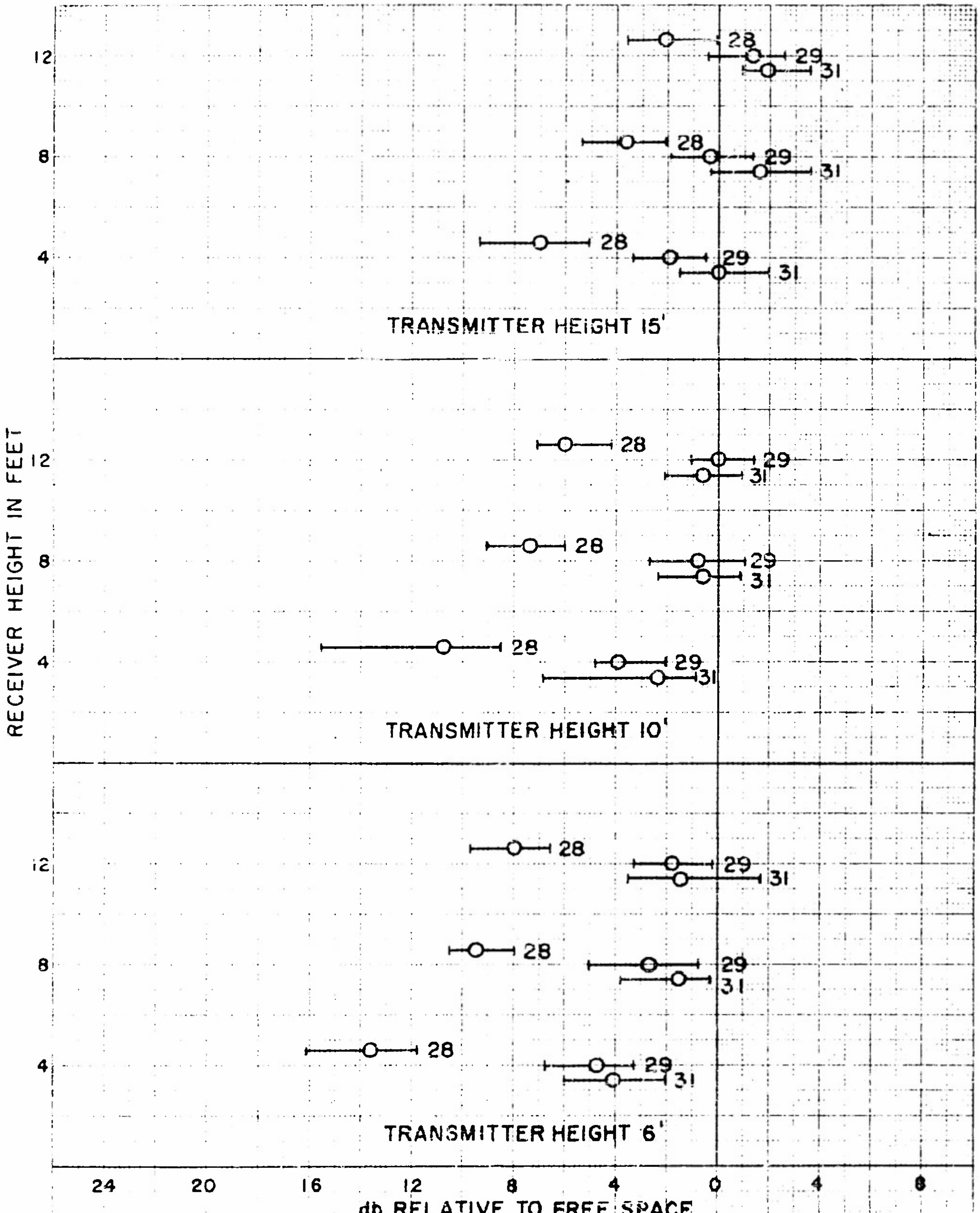
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 4.3 mm WAVELENGTH OVER 38,300 FT. PATH

FIG. A1



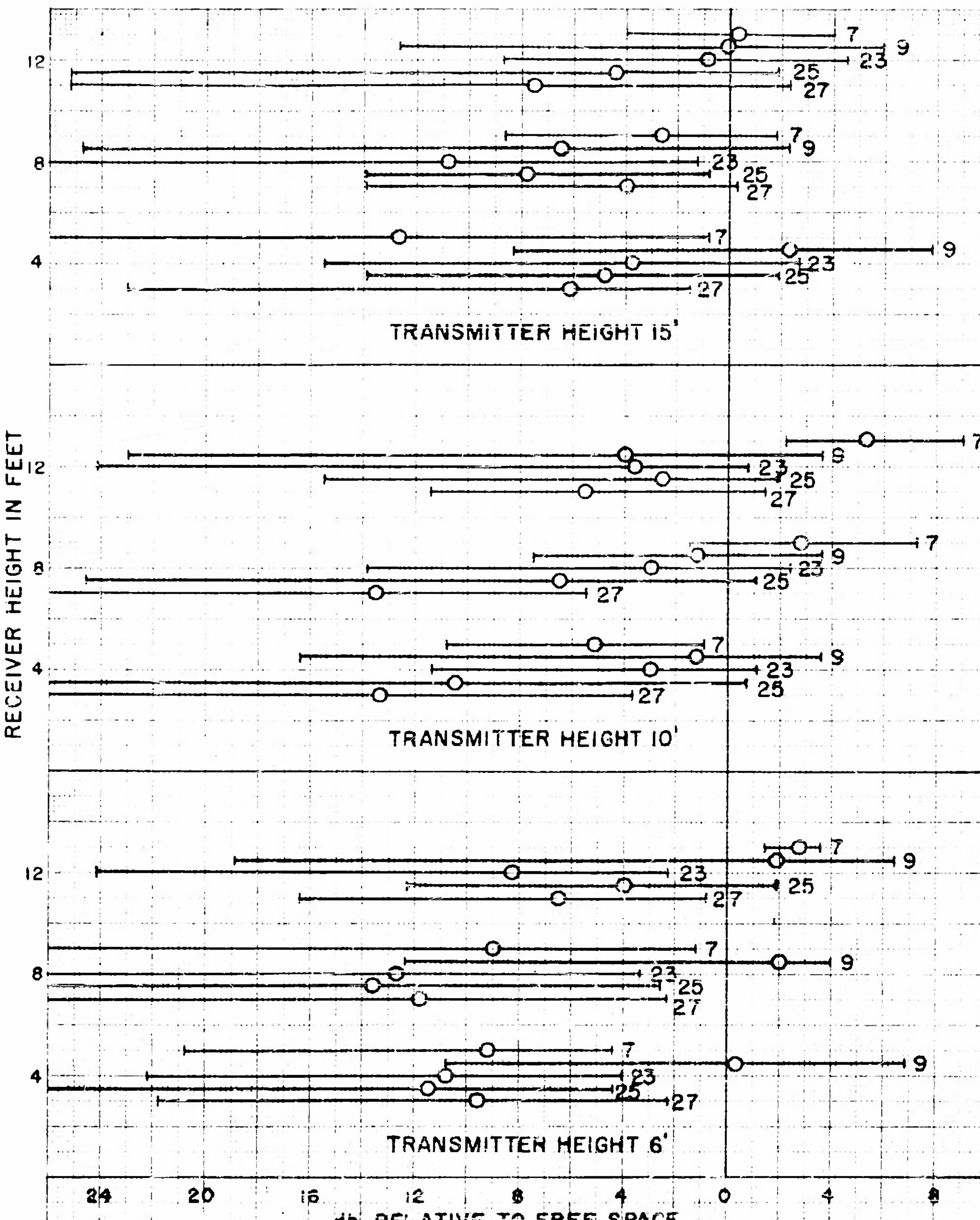
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 8.6mm WAVELENGTH OVER 38,300 FT. PATH

FIG. A2



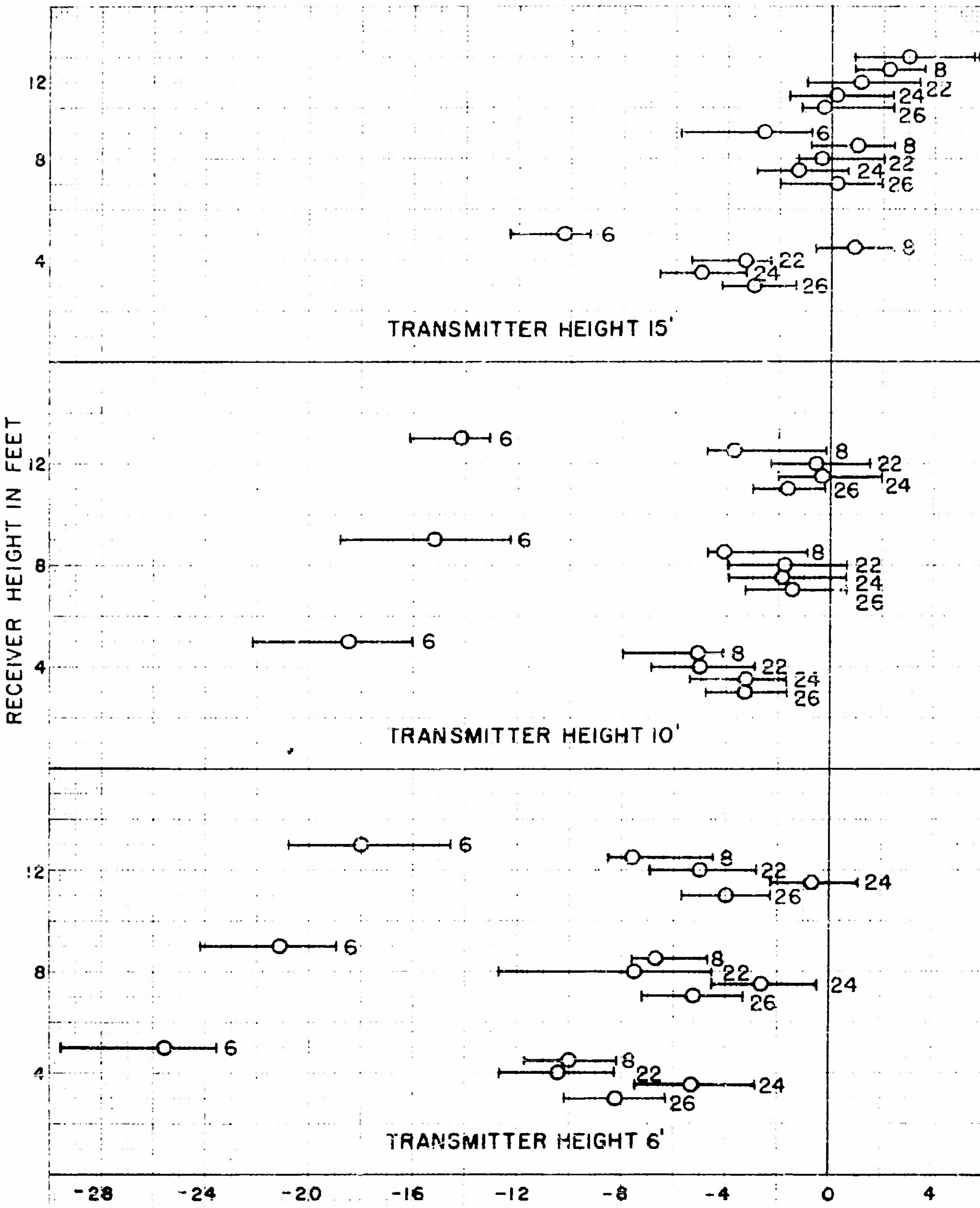
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 3.2 cm WAVELENGTH OVER 38,300 FT PATH

FIG. A3



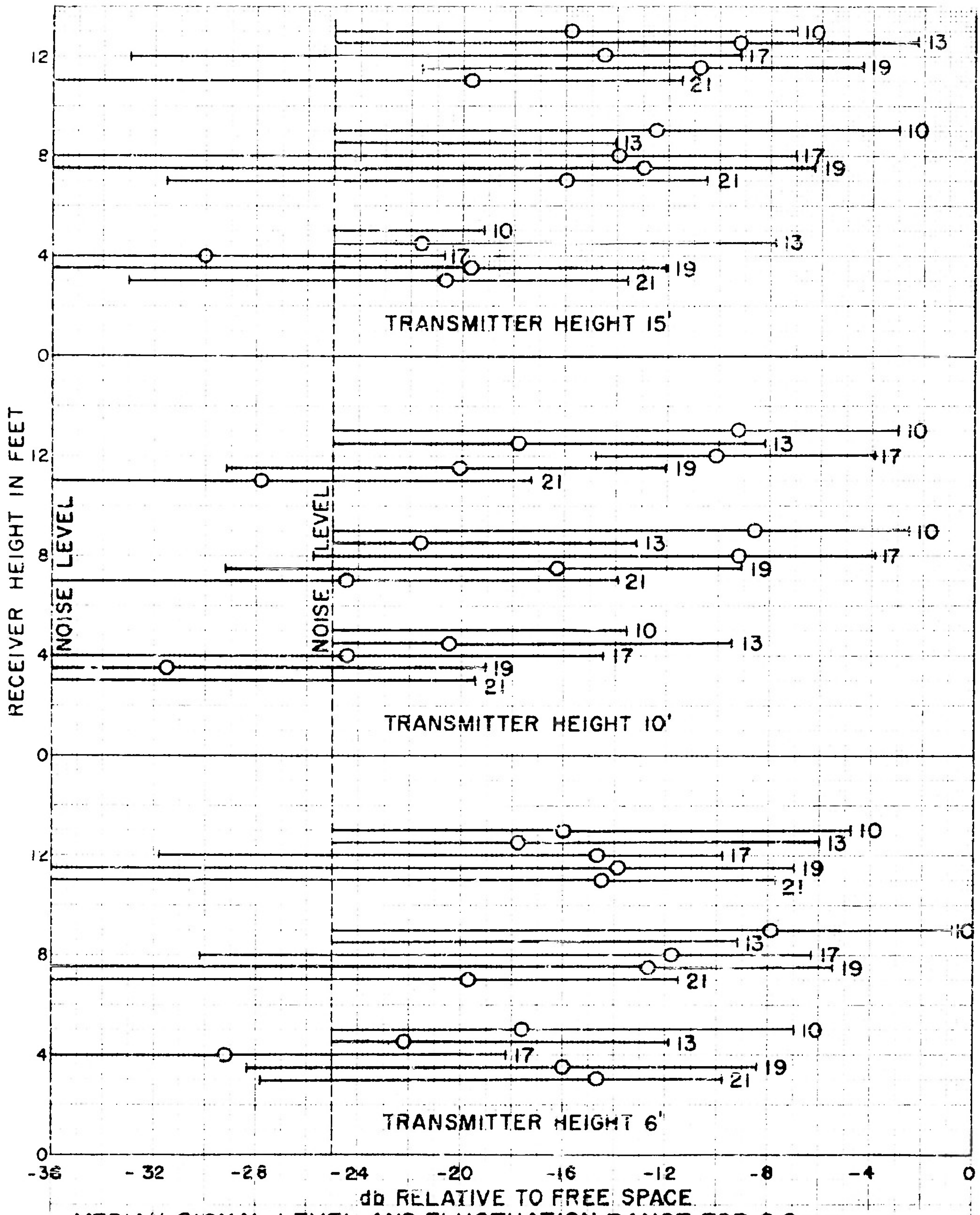
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 8.6 mm WAVELENGTH OVER 64,500 FT. PATH

FIG. A4



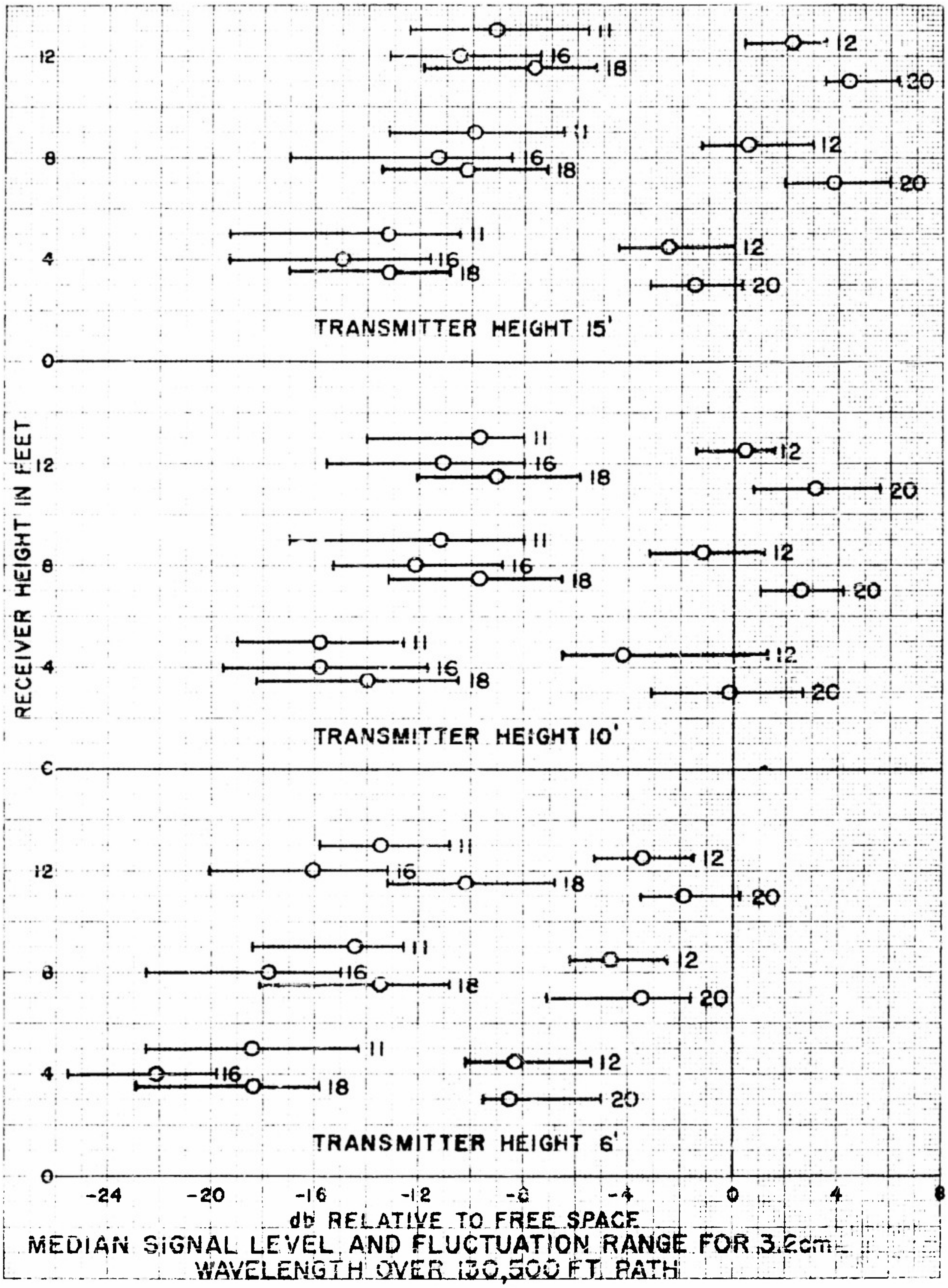
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 3.2 cm. WAVELENGTH OVER 64,500FT. PATH

FIG. A5



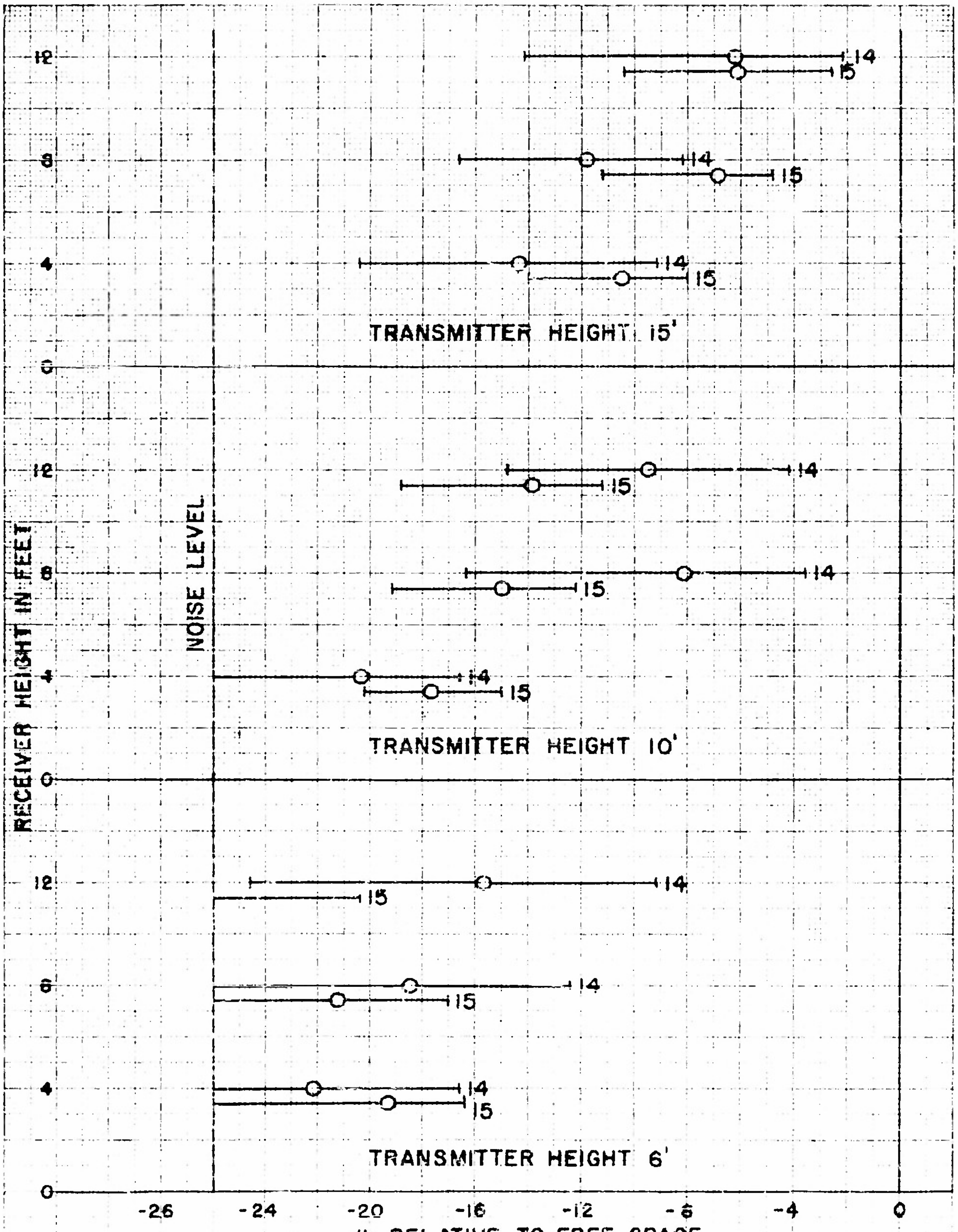
MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 8.6mm WAVELENGTH OVER 130,500FT. PATH

FIG. A6



MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 3.2cm WAVELENGTH OVER 130,500 FT. PATH

FIG. A7



MEDIAN SIGNAL LEVEL AND FLUCTUATION RANGE FOR 3.2cm WAVE LENGTH OVER 236,000FT. PATH

FIG. A8

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